

Claims

Having thus described our invention, what we claim as new and desire to secure by Letters Patents is:

- 1 1. A fault tolerant multichannel communications system having a plurality of communication channels transmitted over a transmission medium, said communications system comprising:
 - 4 (a) a plurality of line cards $1, 2, \dots, N$ at each end of a transmission medium, with one 5 of said line cards at each end of said transmission medium for each of said channels 6 and with one of said line cards s at each end of said medium being designated as 7 a spare line card, each said line card having a plurality of local ports, a link port, 8 and a input/output port;
 - 9 (b) a plurality of switches with one switch at each end of said medium for each of said 10 line cards, each switch capable for interconnecting a link port of a corresponding 11 one of said line cards to an I/O port or a local port of latter said corresponding 12 one line card, and each switch also capable of interconnecting said I/O port to 13 either said link port or a local port of said corresponding one line card, with a local 14 port of each line card i being hard wired to a local port of line card $i + 1 \bmod N$ 15 and a local port of line card $i - 1 \bmod N$; and
 - 16 (c) means for rerouting the I/O of a failed line card f as follows: for each line card 17 i belonging to a set $[s, f]$ of line cards, switching the I/O port of line card $(i + 19$ $1) \bmod N$ to a link port of line card i , where $s \neq f$, wherein said failed channel is restored, where said set $[s, f]$ is the set of all line cards such that

$$[s, f) = \begin{cases} \{s, s + 1, \dots, f - 1\}, & \text{if } s < f; \\ \{s, s + 1, \dots, N - 1, 0, 1, \dots, f - 1\}, & \text{if } s > f; \\ \emptyset, & \text{if } s = f. \end{cases}$$

- 1 2. A fault tolerant multichannel communications system having a plurality of communication channels, said communications system comprising:

3 (a) a plurality of line cards $1, 2, \dots, N$ at each end of said communications medium,
 4 with one of said line cards at each end of said medium for each of said channels
 5 and with one of said line cards s at each end of said medium being designated as
 6 a spare line card, each said line card having a plurality of local ports for a link
 7 port, and a input/output port for;

8 (b) a plurality of switches with one switch at each end of said medium for each of said
 9 line cards, each switch capable for interconnecting a link port of a corresponding
 10 one of said line cards to an I/O port or a local port of latter said corresponding
 11 one line card, and each switch also capable of interconnecting said I/O port to
 12 either said link port or a local port of said corresponding one line card, with a local
 13 port of each line card i being hard wired to a local port of line card $i + 1 \bmod N$
 14 and a local port of line card $i - 1 \bmod N$; and

15 (c) means for rerouting a failed line card f as follows:
 16 for each line card belonging to a set of line cards $[f, s]$, switching the I/O port of
 17 line card i to a link port of line card $(i + 1) \bmod N$, where $s \neq f$ wherein said
 18 failed channel is restored, where $[f, s]$ is the set of all line cards such that

$$[f, s] = \begin{cases} \{f, f + 1, \dots, f - 1\}, & \text{if } f < s; \\ \{f, f + 1, \dots, N - 1, 0, 1, \dots, s - 1\}, & \text{if } f > s; \\ \emptyset, & \text{if } f = s. \end{cases}$$

1 3. In a multichannel communications system having N channels with line cards 0 through
 2 $N - 1$ connected to each end of a transmission medium of said system with each line
 3 card having an I/O port, a link port and a plurality of local ports, with one line card
 4 connected to each end of said transmission medium for each of said channels, a method
 5 of rerouting channels upon detection of a failure of two of said line cards f_0 and f_1 ,
 6 said method comprising:

7 (a) designating two of said line cards as spare line cards s_0 and s_1 ;

8 (b) hardwiring one of said local ports of each line card $i \bmod N$ to one of said local
 9 ports of each line card $(i + 1) \bmod N$ and $(i - 1) \bmod N$;

10 (c) rerouting said failed line cards f_0 and f_1 as follows:

11 i. if $s_0 \leq f_0 \leq f_1 \leq s_1$ then doing spare-to-failed rerouting from s_0 to f_0 and
12 failed-to-spared rerouting from s_1 to f_1 , and

13 ii. if $s_0 \leq f_0 \leq s_1 \leq f_1$ then doing spare-to-failed rerouting from s_0 to f_0 and
14 spare-to-failed rerouting from s_1 to f_1 ,

15 said spare-to-failed rerouting comprising switching each said I/O port of line
16 card $(i + 1) \bmod N$ to said link port of line card $i \bmod N$ for all $i \in [s, f]$,
17 where:

$$18 \quad 19 \quad 20 \quad [s, f) = \begin{cases} \{s, s + 1, \dots, f - 1\}, & \text{if } s < f; \\ \{s, s + 1, \dots, N - 1, 0, 1, \dots, f - 1\}, & \text{if } s > f; \\ \emptyset, & \text{if } s = f, \end{cases}$$

21 and said failed-to-spare rerouting from f to s comprising switching said I/O
22 port of line card $i \bmod N$ to said link port of line card $(i + 1) \bmod N$ for all
23 $i \in [f, s]$, where:

$$24 \quad 25 \quad 26 \quad [f, s) = \begin{cases} \{f, f + 1, \dots, f - 1\}, & \text{if } f < s; \\ \{f, f + 1, \dots, N - 1, 0, 1, \dots, s - 1\}, & \text{if } f > s; \\ \emptyset, & \text{if } f = s. \end{cases}$$

1 4. A fault tolerant multichannel communication system, comprising:

2 (a) a transmission medium;

3 (b) N line cards 0 through $N - 1$, each line card connecting a separate channel to an
4 end of said transmission medium, each line card having an I/O port, a link port,
5 and a plurality of local ports, with two of said line cards s_0 and s_1 being designated
6 as spare line cards, with one of said local ports of each line card $i \bmod N$ being
7 connected to one of said local ports of line card $(i + 1) \bmod N$ and line card
8 $(i - 1) \bmod N$;

9 (c) A plurality of switches, each of said switches for interconnecting said I/O port,
10 said link port, and said local ports of a corresponding one of said line cards; and

11 (d) a means for rerouting I/Os from failed line cards f_0 and f_1 using said switches as
 12 follows:

13 i. if $s_0 \leq f_0 \leq f_1 \leq s_1$ then doing spare-to-failed rerouting from s_0 to f_0 and
 14 failed-to-spared rerouting from s_1 to f_1 , and

15 ii. if $s_0 \leq f_0 \leq s_1 \leq f_1$ then doing spare-to-failed rerouting from s_0 to f_0 and
 16 spare-to-failed rerouting from s_1 to f_1 ,

17 said spare-to-failed rerouting comprising switching each said I/O port of line
 18 card $(i + 1) \bmod N$ to said link port of line card $i \bmod N$ for all $i \in [s, f]$,
 19 where:

$$[s, f) = \begin{cases} \{s, s + 1, \dots, f - 1\}, & \text{if } s < f; \\ \{s, s + 1, \dots, N - 1, 0, 1, \dots, f - 1\}, & \text{if } s > f; \\ \emptyset, & \text{if } s = f, \end{cases}$$

23 and said failed-to-spare rerouting from f to s comprising switching said I/O
 24 port of line card $i \bmod N$ to said link port of line card $(i + 1) \bmod N$ for all
 25 $i \in [f, s]$, where:

$$[f, s) = \begin{cases} \{f, f + 1, \dots, f - 1\}, & \text{if } f < s; \\ \{f, f + 1, \dots, N - 1, 0, 1, \dots, s - 1\}, & \text{if } f > s; \\ \emptyset, & \text{if } f = s. \end{cases}$$

1 5. In a multichannel communications system having N channels with line cards 0 through
 2 $N - 1$ connected to each end of a transmission medium of said system with each line
 3 card having an I/O port, a link port and a plurality of local ports, with one line card
 4 connected to each end of said transmission medium for each of said channels, a method
 5 of rerouting channels upon detection of a failure of one of said line cards, said method
 6 comprising:

7 (a) partitioning said line cards into groups of size at most $k + 1$, where each group
 8 has at least one spare line card, and where k equals the number of local ports on
 9 each line card;

10 (b) for each line card in each of said groups that is not a spare line card, hardwiring
11 one of latter said each line card's local ports to a local port of said one spare line
12 card in said each group; and

13 (c) upon detection of a failure of any of said line cards, rerouting said I/O port of
14 latter said failed line card to the link port of said designated spare line card for
15 the group of line cards containing said failed line card.

1 6. In a multichannel communications system having N channels with line cards 0 through
2 $N - 1$ connected to each end of a transmission medium of said system with each line
3 card having an I/O port, a bypass port, a link port and a plurality of k local ports
4 where $k < N$, with one line card connected to each end of said transmission medium
5 for each of said channels, a method of rerouting channels upon detection of a failure
6 of one of said line cards, said method comprising:

7 (a) designating one of said line cards as a spare line card s ;
8 (b) hard wiring the local ports of each of said line cards such that there is a path
9 from each of said line cards to said spare line card; and
10 (c) rerouting the I/O port of a failed line card by switching said I/O port of said
11 failed line card to its said bypass port which is hard wired to said local port of
12 another one of said line cards and switching said latter local port to said link port
13 of spare line card s .

1 7. A fault tolerant multichannel communication system, comprising:

2 (a) a transmission medium;
3 (b) N line cards 0 through $N - 1$, each line card connecting a separate channel to
4 an end of said transmission medium, each line card having an I/O port, a bypass
5 port, a link port, and a plurality of k local ports where $k < N$, with one of said
6 line cards being designated as spare line card s , with said local ports of said line
7 cards being hardwired so that there is a path from each of said line cards to line
8 card s ;

9 (c) A plurality of switches, each of said switches for interconnecting said I/O port,
10 said bypass port, said link port, and said local ports of a corresponding one of
11 said line cards; and

12 (d) a means for rerouting I/Os from a failed one of said line cards by using said one
13 of said switches corresponding to said line card to switch said I/O port of said
14 failed line card to its said bypass port which is hardwired to said local port of
15 another one of said line cards and switching said latter local port to said link port
16 of spare line card s.

1 8. In a multichannel communications system having N channels with line cards 0 through
2 $N - 1$ connected to each end of a transmission medium of said system with each line
3 card having an I/O port, a bypass port, a link port and a plurality of local ports,
4 with one line card connected to each end of said transmission medium for each of said
5 channels, a method of rerouting channels upon detection of a failure of one of said line
6 cards, said method comprising:

7 (a) designating one of said line cards as a spare line card;

8 (b) hard wiring one of said local ports of each of up to k of said line cards to each
9 of said of said spare line cards, where k is the number of local ports each of said
10 line cards;

11 (c) hard wiring said local ports of each of said line cards hard wired to said local
12 ports of said spare line card to an additional $k - 1$ of said line cards;

13 (d) repeating step 8c for each line card of said $k - 1$ line cards by hard wiring each
14 of latter said line cards in turn to an additional $k - 1$ of said line cards and so on
15 until all of said line cards form a tree configuration with a plurality of subtrees;

16 (e) hard wiring the bypass port of each line card that is a leaf of said tree configuration
17 to the local port of another line card that is a leaf of said tree configuration;

18 (f) hard wiring the bypass port of each of said line cards that is not a leaf to the local
19 port of a line card that is a leaf; and

20 (g) rerouting the I/O port of a failed one of said line cards by switching its I/O port
21 to its bypass port and switching appropriate local ports of said line cards so that
22 said I/O port of said failed line card is connected to said link port of said spare
23 line card.

1 9. In a multichannel communications system having N channels with line cards 0 through
2 $N - 1$ connected to each end of a transmission medium of said system with each line
3 card having an I/O port, a bypass port, a link port and a plurality of k local ports
4 where $k < N$, with one line card connected to each end of said transmission medium
5 for each of said channels, a method of rerouting channels upon detection of a failure
6 of two of said line cards, said method comprising:

7 (a) designating two of said line cards as spare line cards s_1 and s_2 ;
8 (b) hardwiring said local ports of each of said line cards such that for any pair of line
9 cards f_1 and f_2 there are either two paths p_1 from f_1 to s_1 and p_2 from f_2 to s_2
10 where p_1 and p_2 have no common wires, or two paths p_1 from f_1 to s_2 and p_2 from
11 f_2 to s_1 where p_1 and p_2 have no common wires;
12 (c) rerouting the I/O of up to two failed line cards by switching the I/O of said failed
13 line cards to said spare cards by setting switches along paths from said failed line
14 cards to said spares, where said paths have no common wires.

1 10. A fault tolerant multichannel communication system, comprising:

2 (a) a transmission medium;
3 (b) N line cards 0 through $N - 1$, each line card connecting a separate channel to
4 an end of said transmission medium, each line card having an I/O port, a bypass
5 port, a link port, and a plurality of k local ports $k < N$, with two of said line
6 cards being designated as spare line cards s_1 and s_2 , with said local ports of said
7 line cards being hardwired such that for any pair of line card f_1 and f_2 there are
8 either two paths p_1 from f_1 to s_1 and p_2 from f_2 to s_2 , where p_1 and p_2 have no
9 common wires, or two paths p_1 from f_1 to s_2 and p_2 from f_2 to s_1 where p_1 and
10 p_2 have no common wires;

- (c) A plurality of switches, each of said switches for interconnecting said I/O port, said bypass port, said link port, and said local ports of a corresponding one of said line cards; and
- (d) a means for rerouting I/Os from up to two failed line cards by setting said switches along of those of said paths from said failed line cards to said spares. where said paths have no common wires.

11. In a multichannel communications system having N channels with line cards 0 through $N - 1$ connected to each end of a transmission medium of said system with each line card having an I/O port, a bypass port, a link port and a plurality of local ports, with one line card connected to each end of said transmission medium for each of said channels, a method of rerouting channels upon detection of failures of up to two of said line cards, said method comprising:

- (a) designating two of said line cards s_1 and s_2 as spare cards;
- (b) hardwiring another one of said line cards i to said local ports of s_1 and s_2 to form a dual tree, where i is a leaf card of said dual tree and s_1 and s_2 are internal cards of said dual tree, and said dual tree comprises two trees T_1 and T_2 , where s_1 and line card i belong to T_1 , and s_2 and line card i belong to T_2 ;
- (c) hardwiring another line card x of said line cards to said dual tree according to the following rules:
 - i. if there are two internal cards j and k belonging to T_1 and T_2 respectively, with each of said cards j and k hardwired to each other by less than $k - 1$ leaf cards then hardwire local ports of line card x to said local ports of j and k , where x is a leaf card of said trees T_1 and T_2 ,
 - ii. if rule 11(c)i cannot be applied, and if a single leaf card l is hardwired to two internal cards i_1 and i_2 belonging to T_1 and T_2 respectively, and any other leaf card m hardwired to two internal cards is at least as far as l is from the furthest spare card, then disconnect l from i_1 , hardwire a local port of x to a local port of i_1 , hardwire a local port of x to a local port of l , where x is now

23 a leaf card belonging to T_1 and l now belongs exclusively to T_2 , and

24 iii. if rules 11(c)i and 11(c)ii cannot be applied, and two leaf cards p and q are

25 hardwired to each other, then disconnect p from q , hardwire local ports of x

26 to local ports of p and q , where x is a leaf card belonging to both T_1 and T_2

27 and p and q become internal cards; and

28 (d) rerouting the I/Os of up to two failed line cards f_1 and f_2 by finding the shortest

29 paths $p_{1,1}$ from f_1 to s_1 , $p_{1,2}$ from f_1 to s_2 , $p_{2,1}$ from f_2 to s_1 , and $p_{2,2}$ from f_2 to

30 s_2 , choosing q_1 as $p_{1,1}$ and q_2 as $p_{2,2}$ if $p_{1,1}$ and $p_{2,2}$ do not have a common wire,

31 and choosing q_1 as $p_{1,2}$ and q_2 as $p_{2,1}$ otherwise, setting switches along said paths

32 q_1 and q_2 such that said I/Os of said failed line cards are routed to the link ports

33 of said spare line cards.